Vehicle Level Model and Control Development and Validation Under Various Thermal Conditions

2014 DOE Hydrogen Program and Vehicle Technologies Annual Merit Review

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Argonne National Laboratory

Sponsored by David Anderson

Project ID #VSS127

U.S. Department of Energy

Energy Efficiency and Renewable Energy

Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

Project Overview

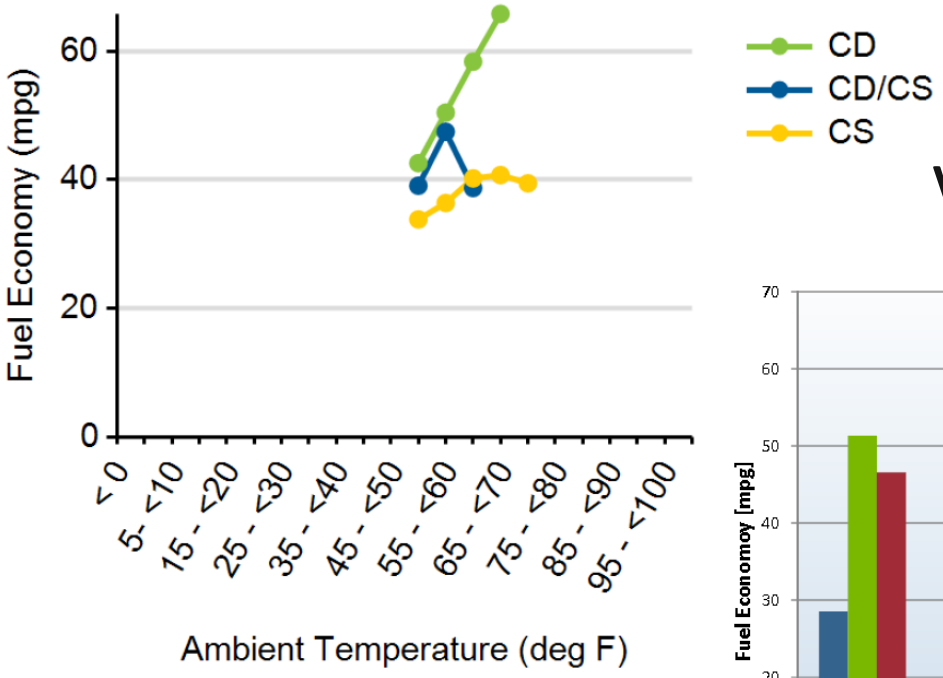
Timeline	Barriers
• Start – September 2011 • End – September 2014 • 80% Complete	• Implement detailed component thermal model • Assess impact of temperature on fuel displacement
Budget	**Partners**
• FY12 $150K • FY13 $300K • FY14 $150K	• Automotive manufacturer • Battery manufacturer • MathWorks • Argonne: APRF, Chemical Division • NREL

Relevance

Temperature Has a Significant Impact on Electric Drive Energy Consumption

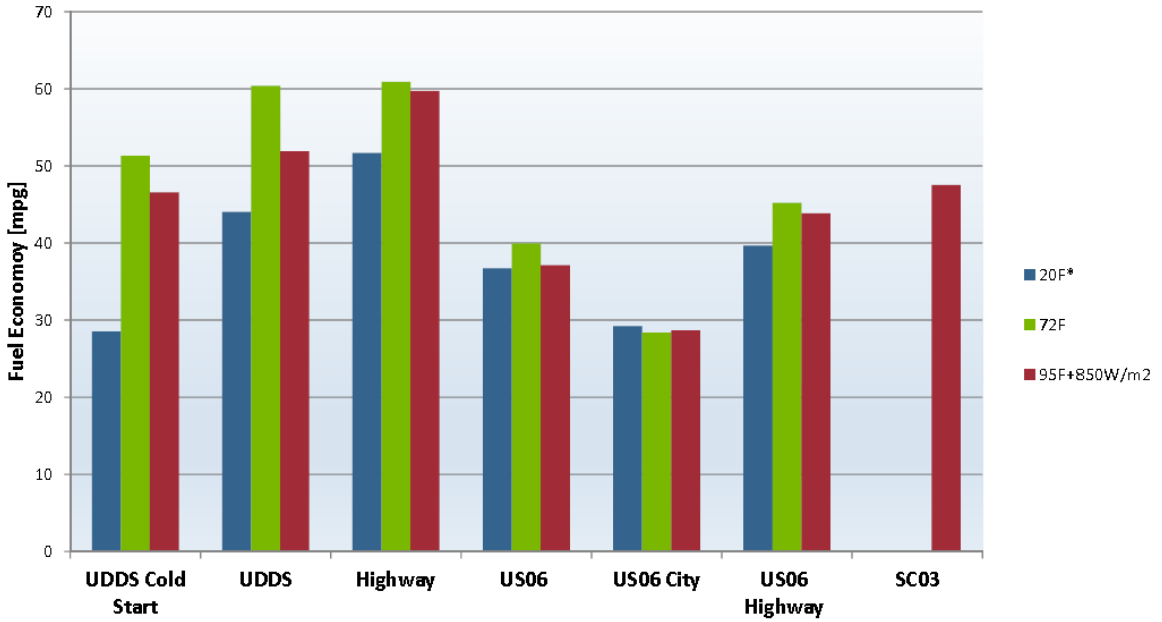
Fleet Evaluation

Source: INL – 2013 Ford Cmax Energi [1]



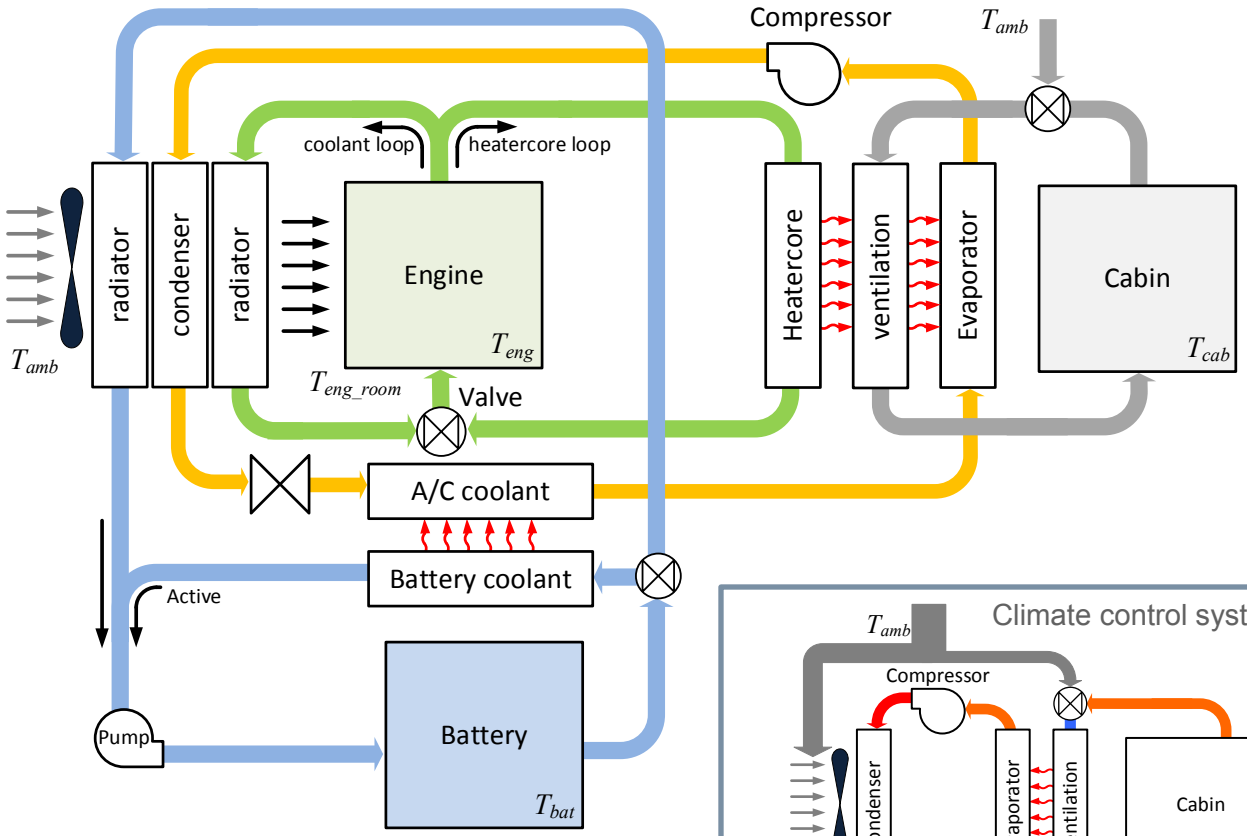
Vehicle Dynamometer Testing

Source: ANL APRF – 2013 Ford Cmax Energi



(1) http://avt.inel.gov/pdf/phev/FordCMaxOct-Dec2013.pdf

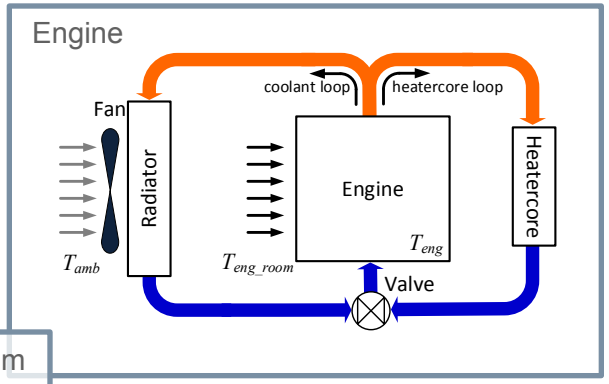
DOE VTO Effort to Develop and Validate Complete Thermal Models Has Been Ongoing for Several Years

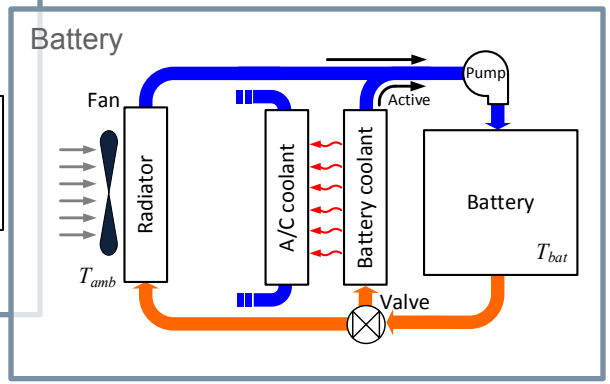


GM Volt

Ford Focus BEV

Toyota Prius HEV





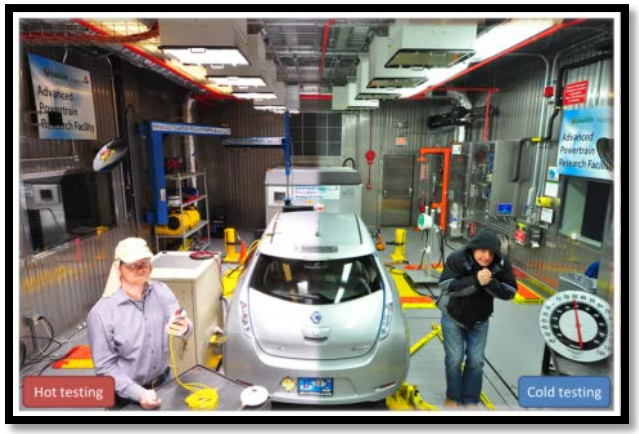
Relevance

The objective is to develop the entire vehicle thermal management system for advanced electric drive vehicles (EREVs, HEVs, EVs, PHEVs).

- Additional energy consumption cased by cold and hot temperatures results in low fuel economy, shorter range and high emissions.
- Vehicle thermal management system (VTMS) model and the vehicle powertrain model are integrated to predict thermal response of the VTMS and fuel economy of the vehicle under various vehicle thermal and driving conditions.
- Validated model will be used to analyze and improve the performance of the VTMS and its fuel economy.

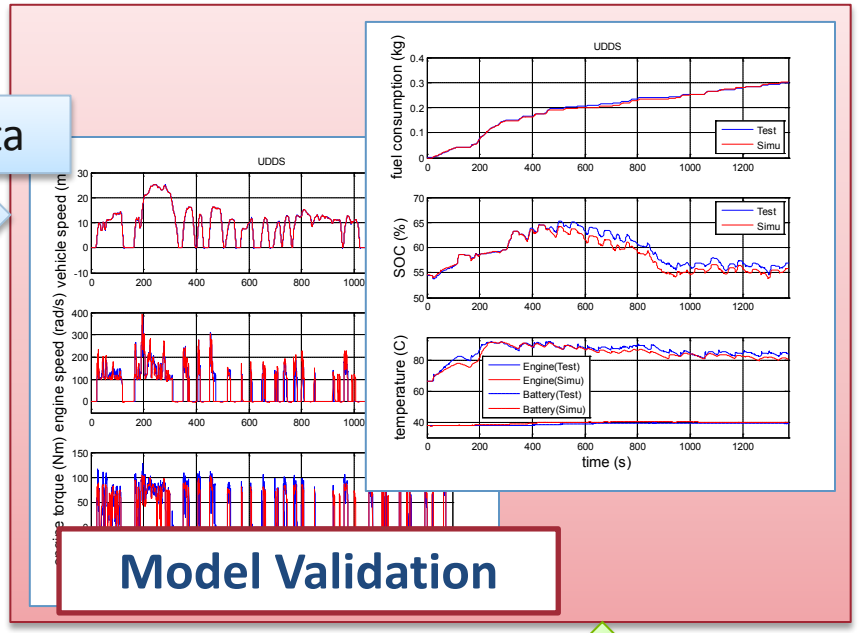
Approach

Test data from ANL APRF



°C
-7
21
35

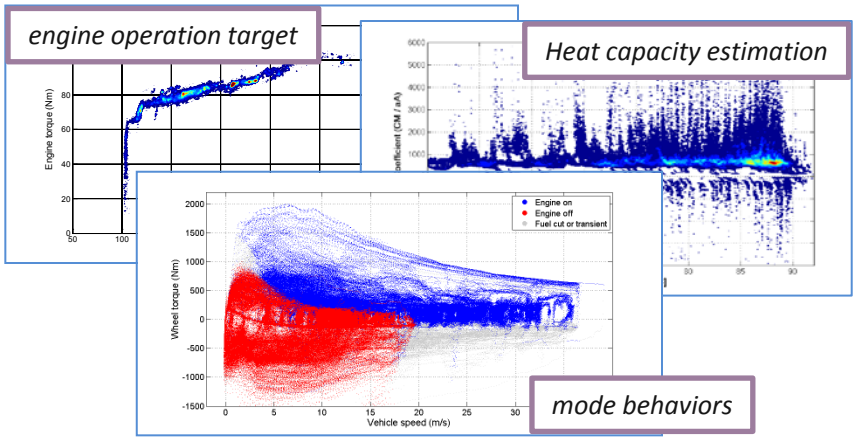
Test data



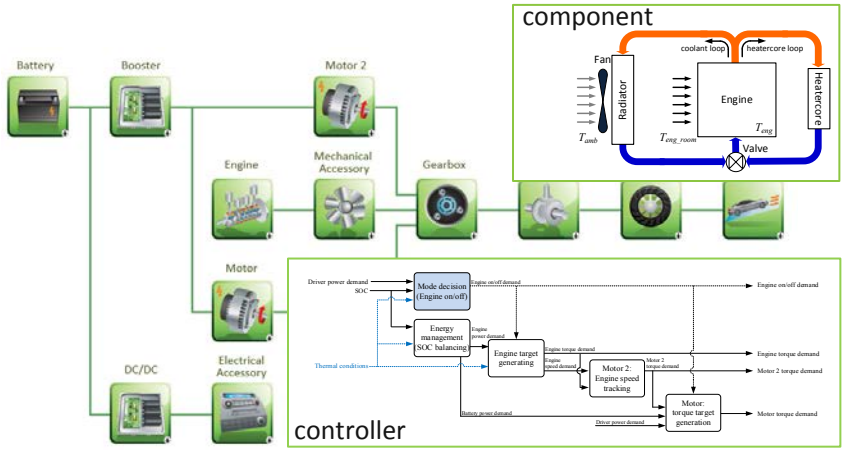
Model Validation

Simulation data

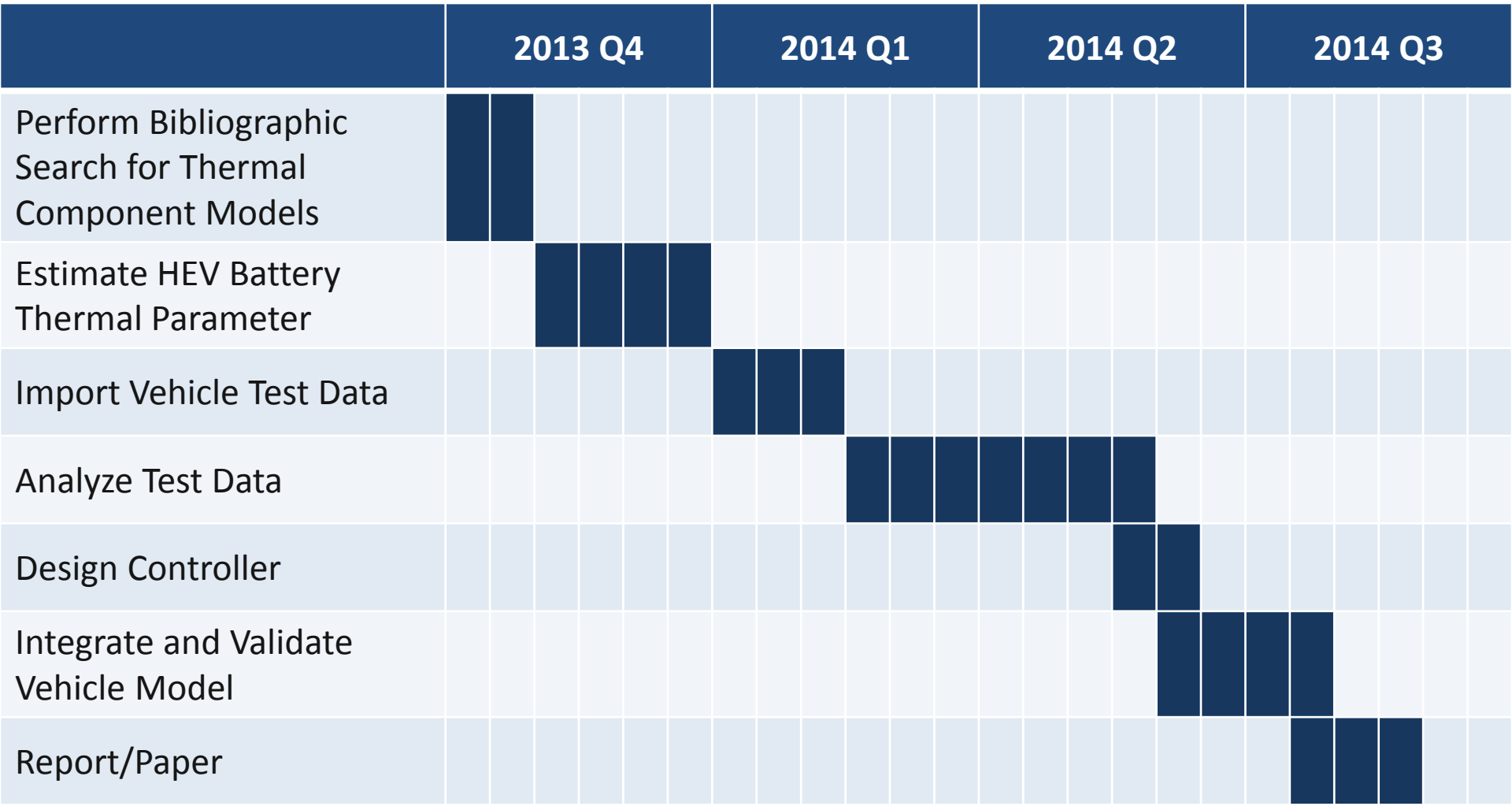
Control and Performance Analysis



Model Development (Autonomie)

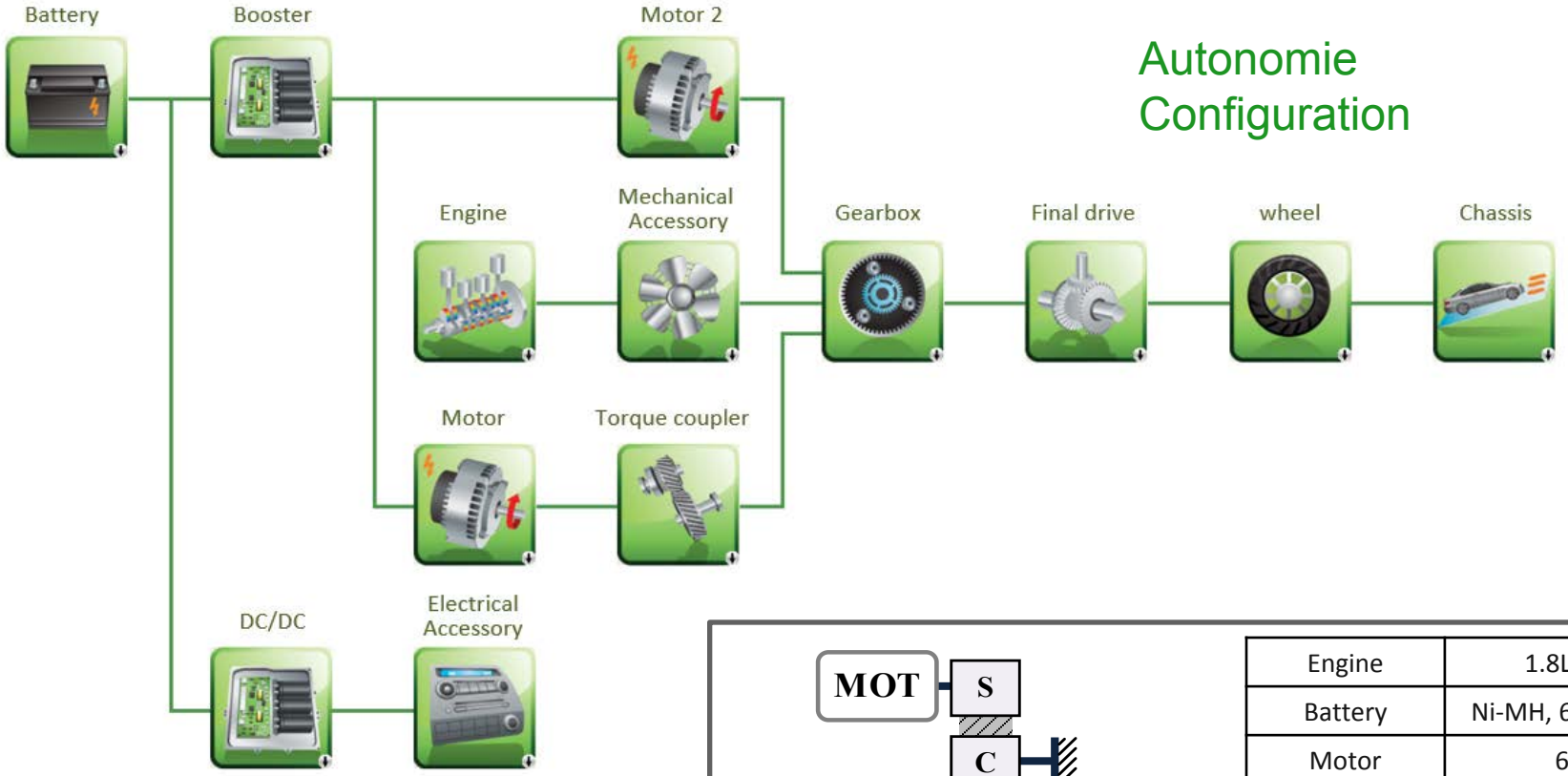


Milestones

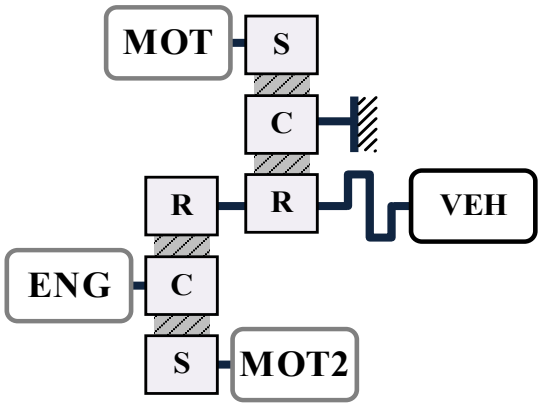

2013 Q4
2014 Q1
2014 Q2
2014 Q3
Perform Bibliographic Search for Thermal Component Models
Estimate HEV Battery Thermal Parameter
Import Vehicle Test Data
Analyze Test Data
Design Controller
Integrate and Validate Vehicle Model
Report/Paper

Technical Accomplishments

2010 Toyota Prius Thermal Vehicle Model



Autonomie Configuration

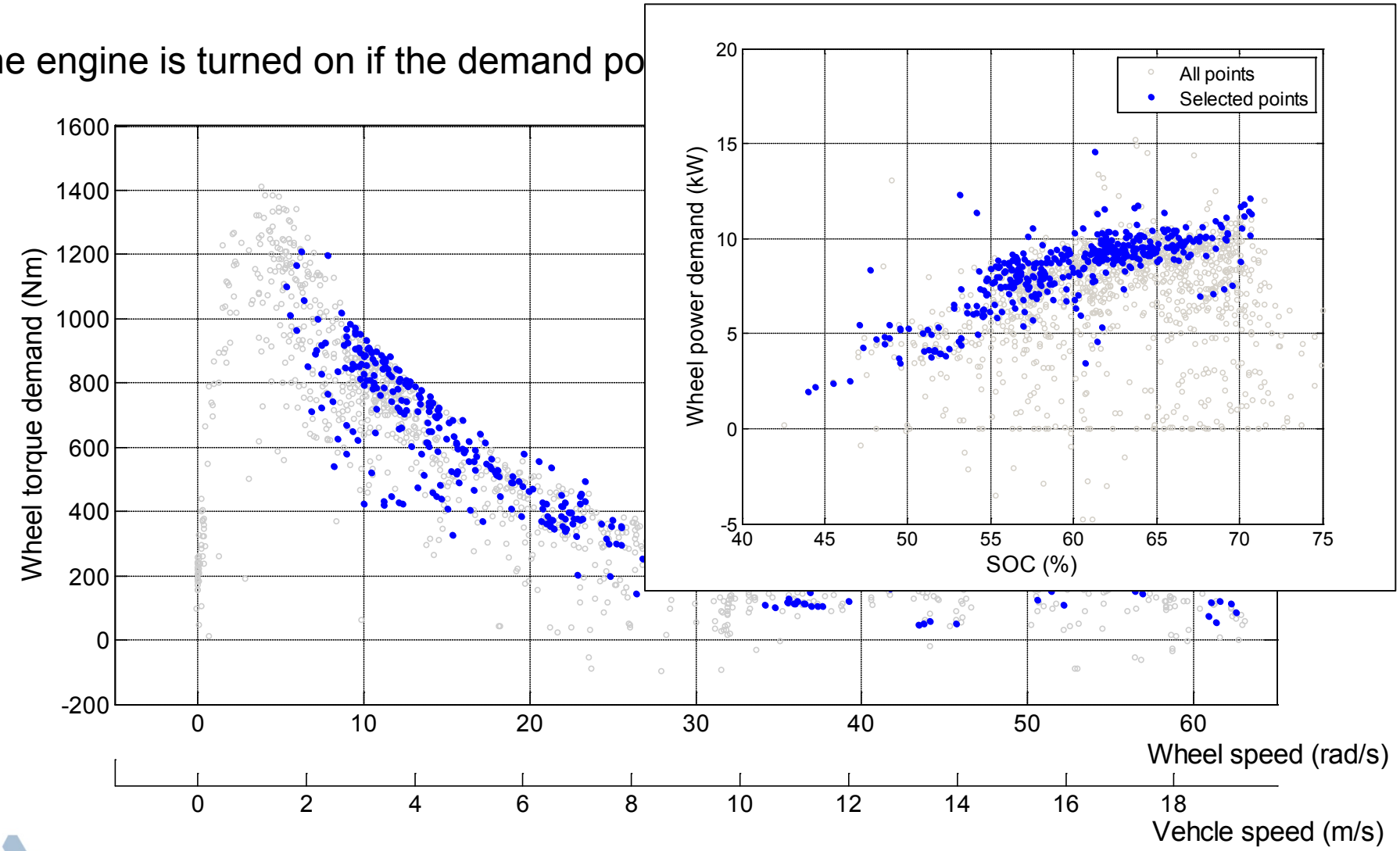


Engine	1.8L, 73kW
Battery	Ni-MH, 6.5Ah, 27kW
Motor	60kW
Net power	100kW
Final drive	3.268
FE (EPA)	50 MPG (comb.), 51/48 MPG (city/hwy)
0-60mph	10.0 s

Technical Accomplishments

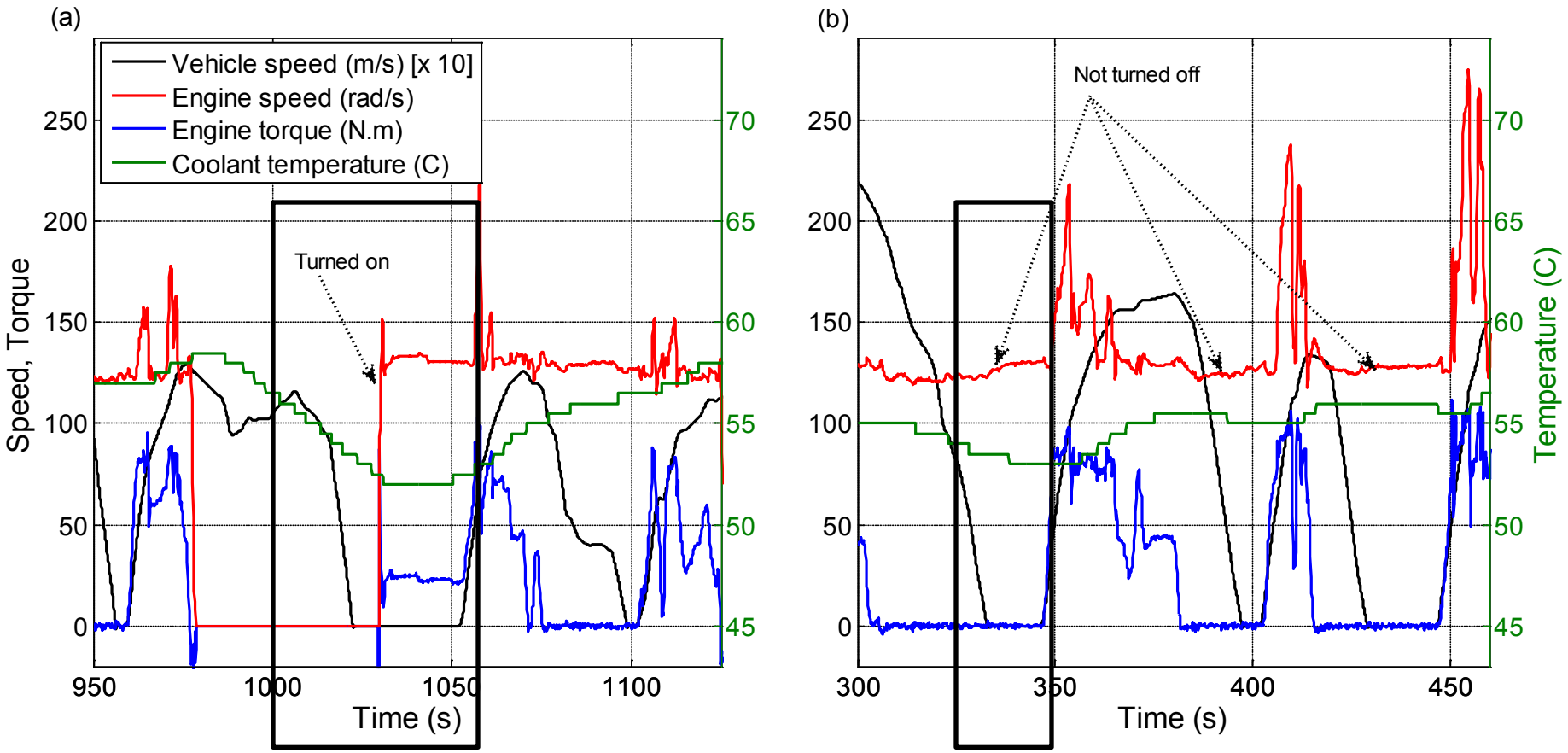
Temperature Impact on Engine ON/OFF Conditions

The engine is turned on if the demand po



Technical Accomplishments

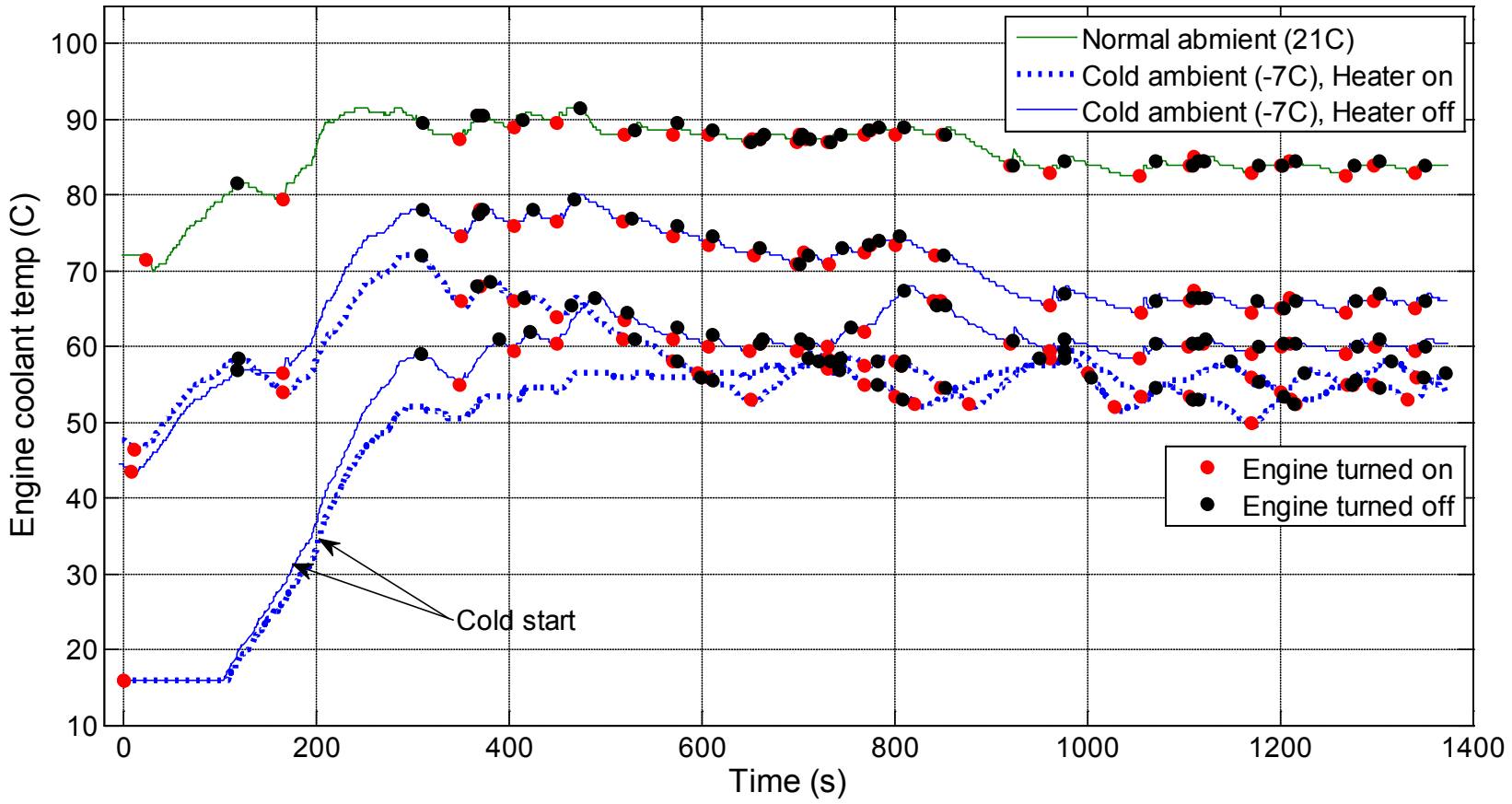
Engine Maintained ON at Low Coolant Temperature



The engine is not turned off if the coolant temperature is low.

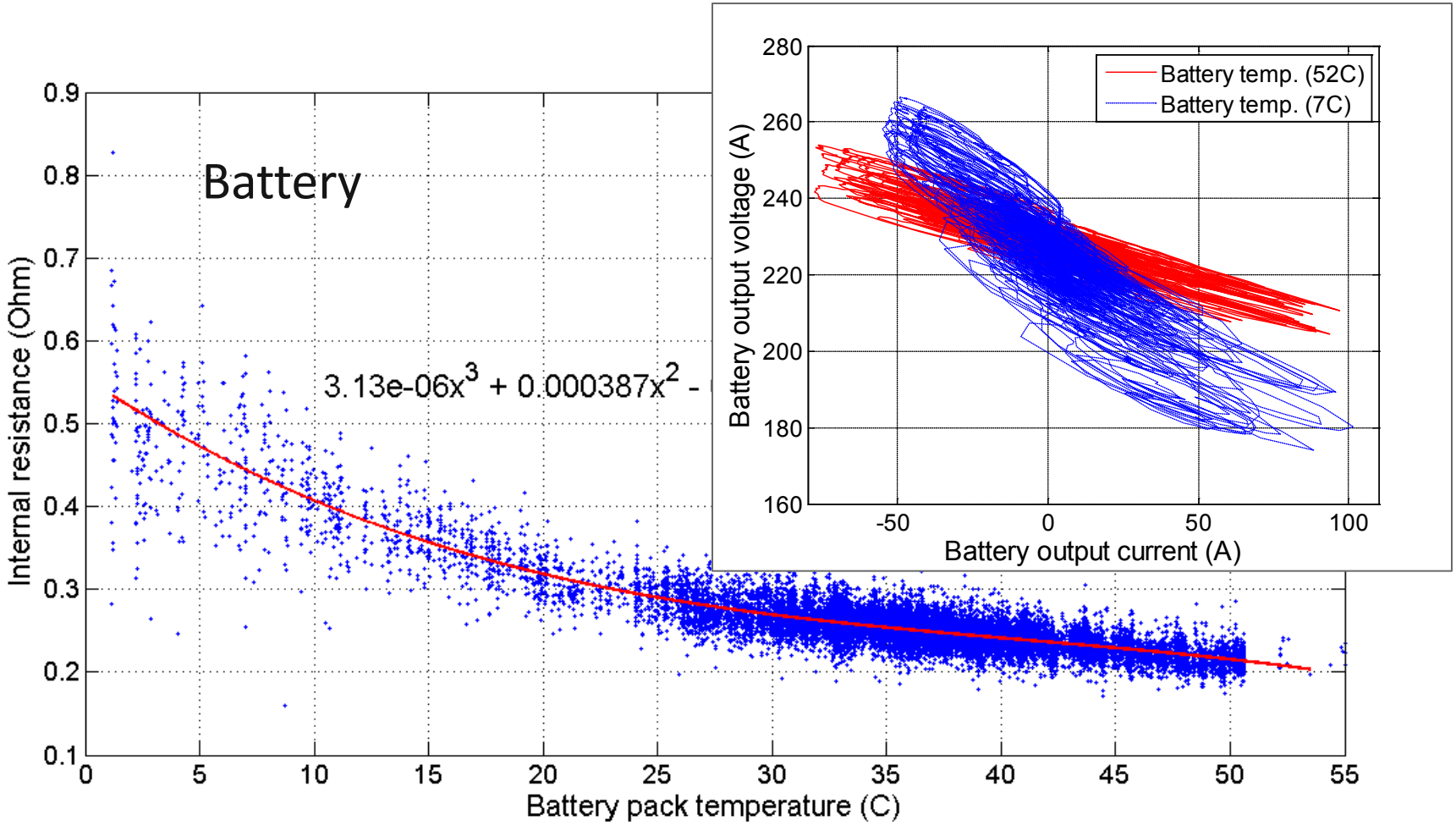
Technical Accomplishments

Engine Coolant Temperature Maintained Above 53C



Technical Accomplishments

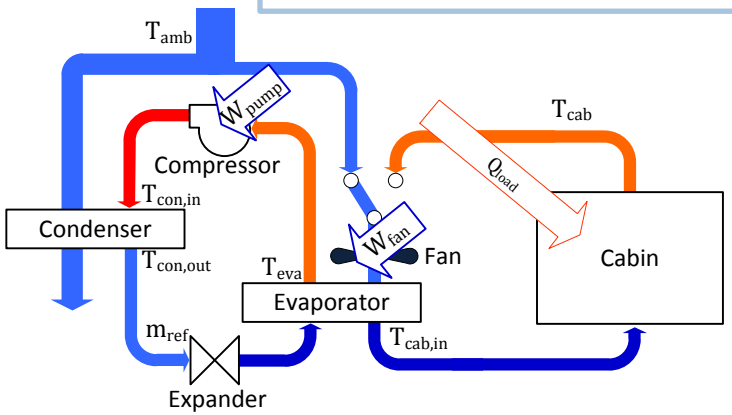
Temperature Impact on Component Performance Characterized

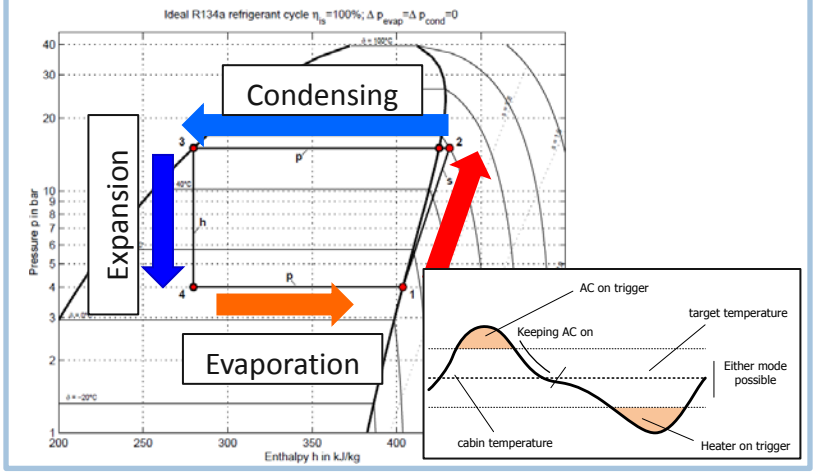


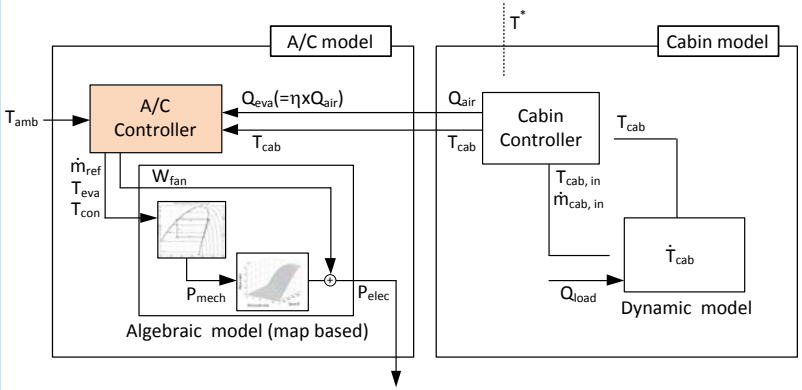
Technical Accomplishments

Individual Component such as Climate Control System Modeled

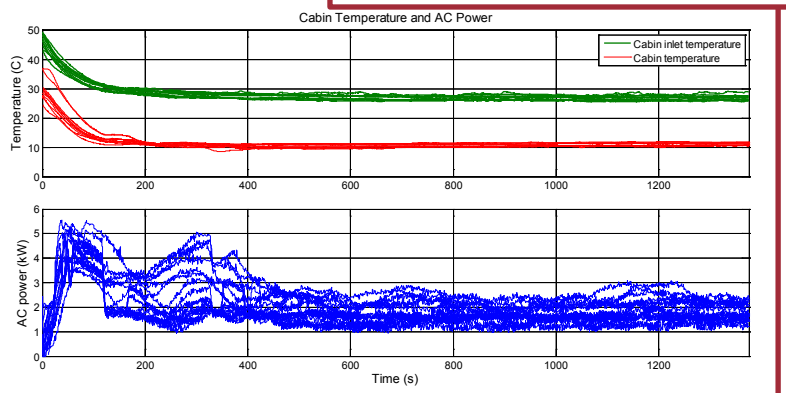
Model development





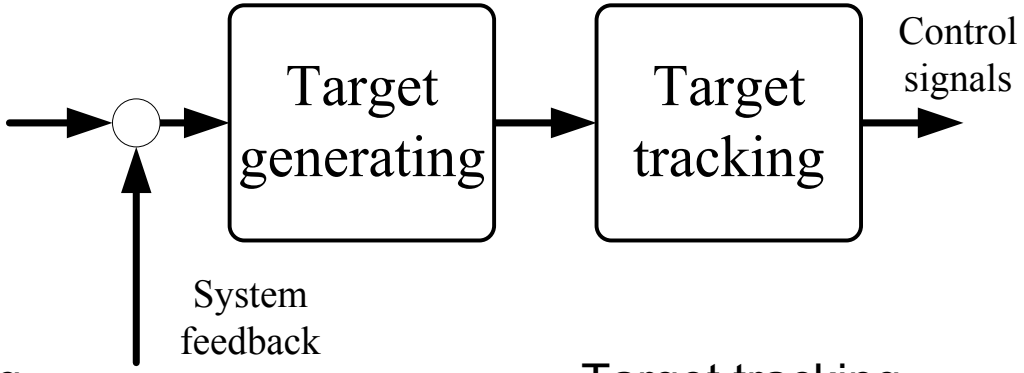


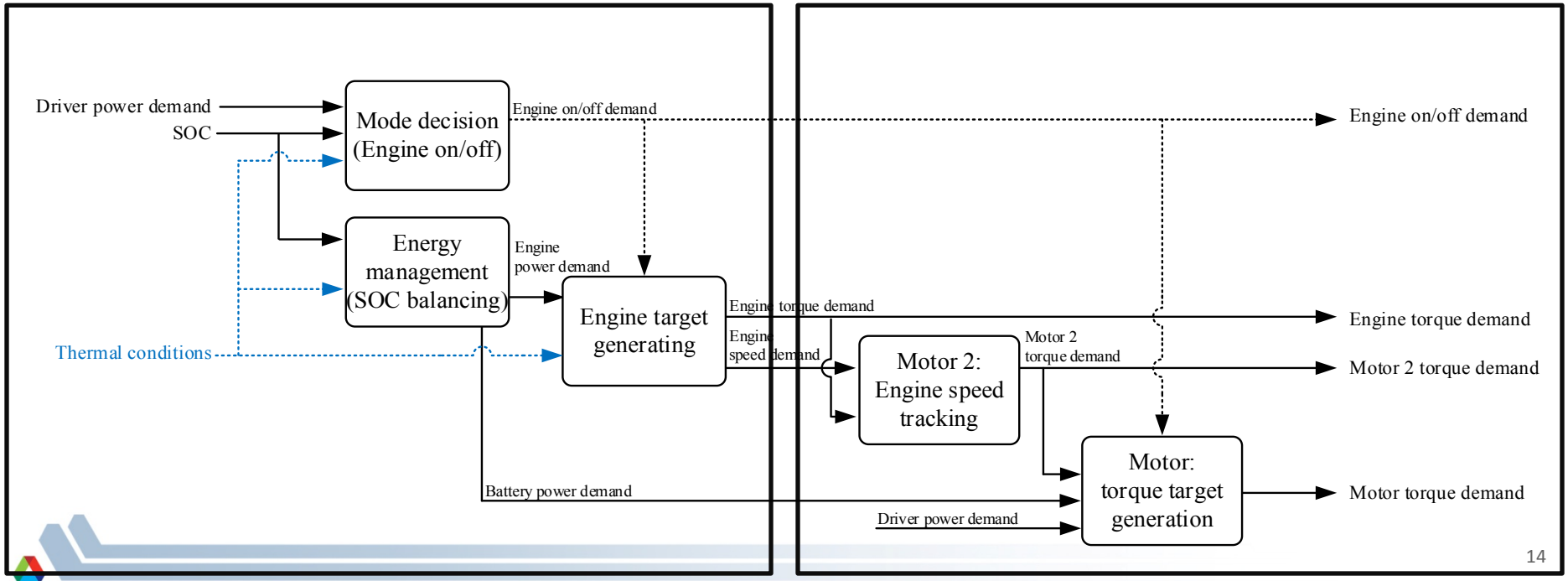
Model validation



Technical Accomplishments

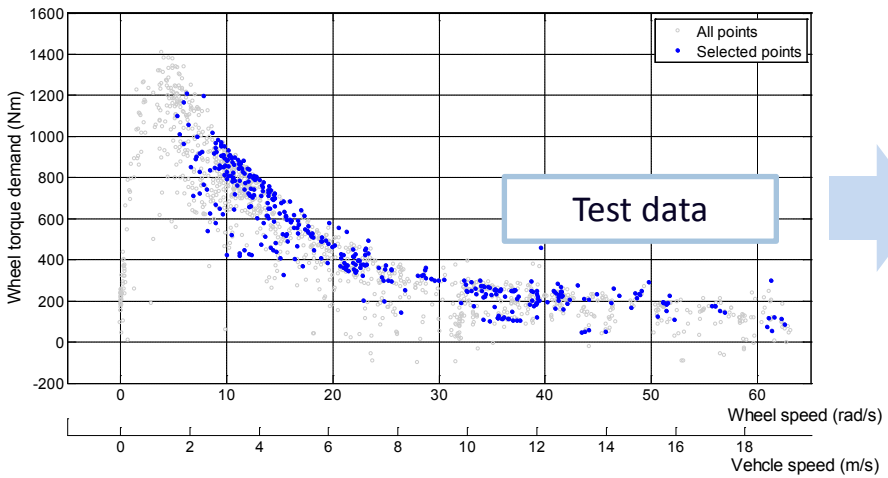
Vehicle Energy Management Developed Based on APRF Data

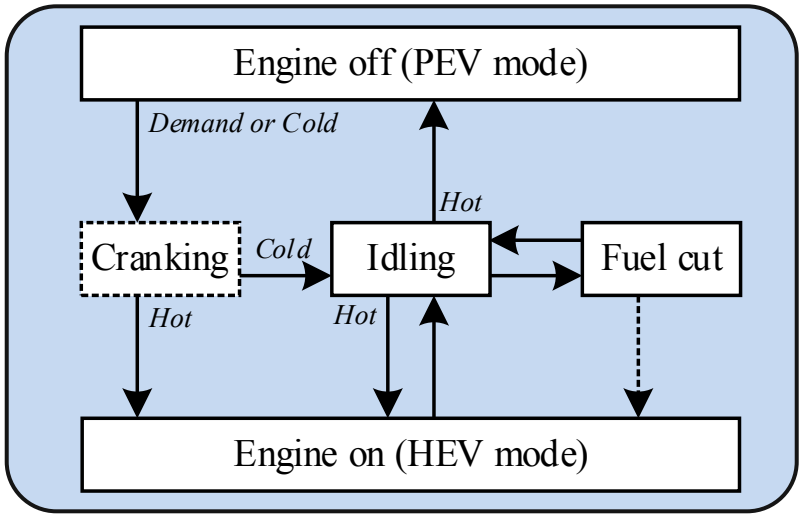


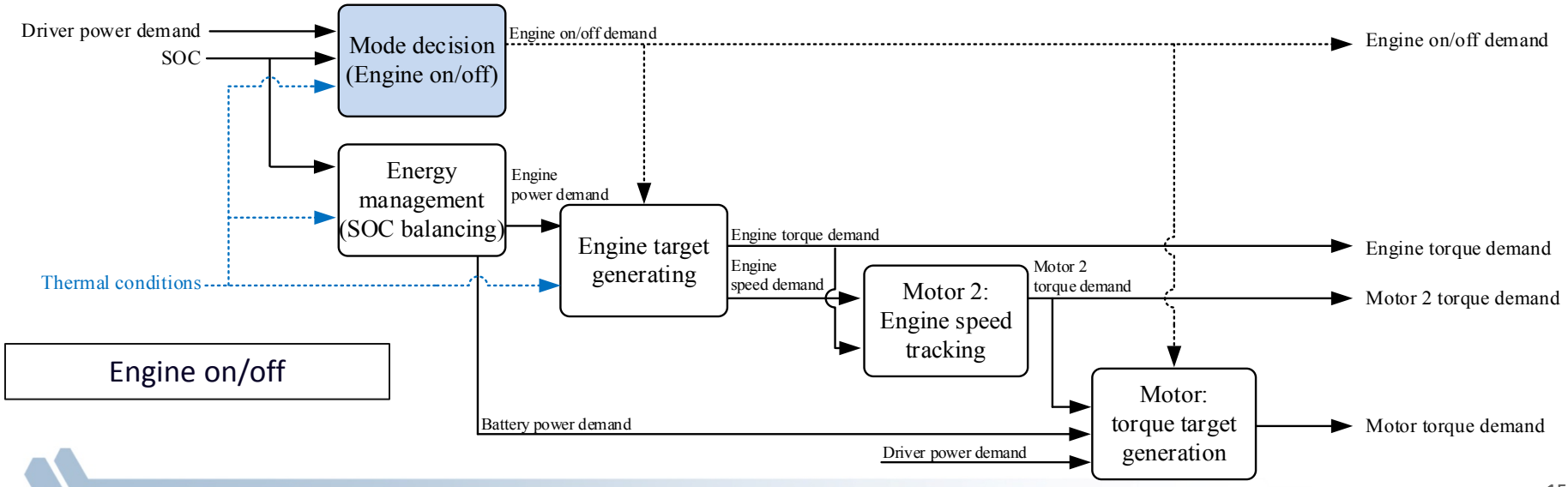


Technical Accomplishments

Analyze the control algorithm based on test data

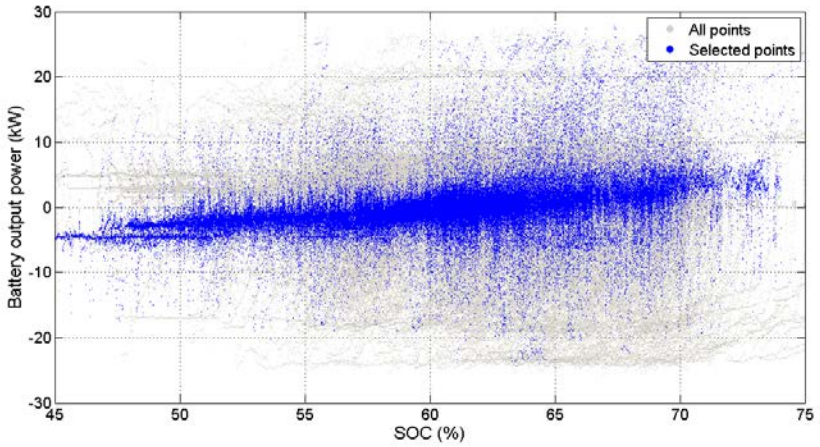


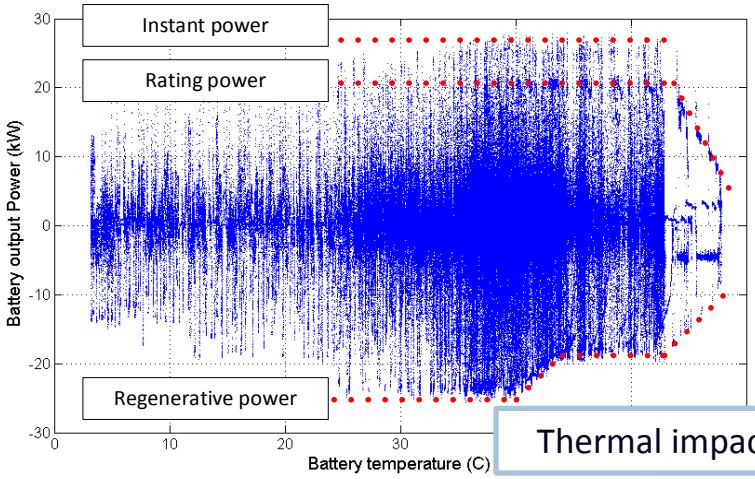




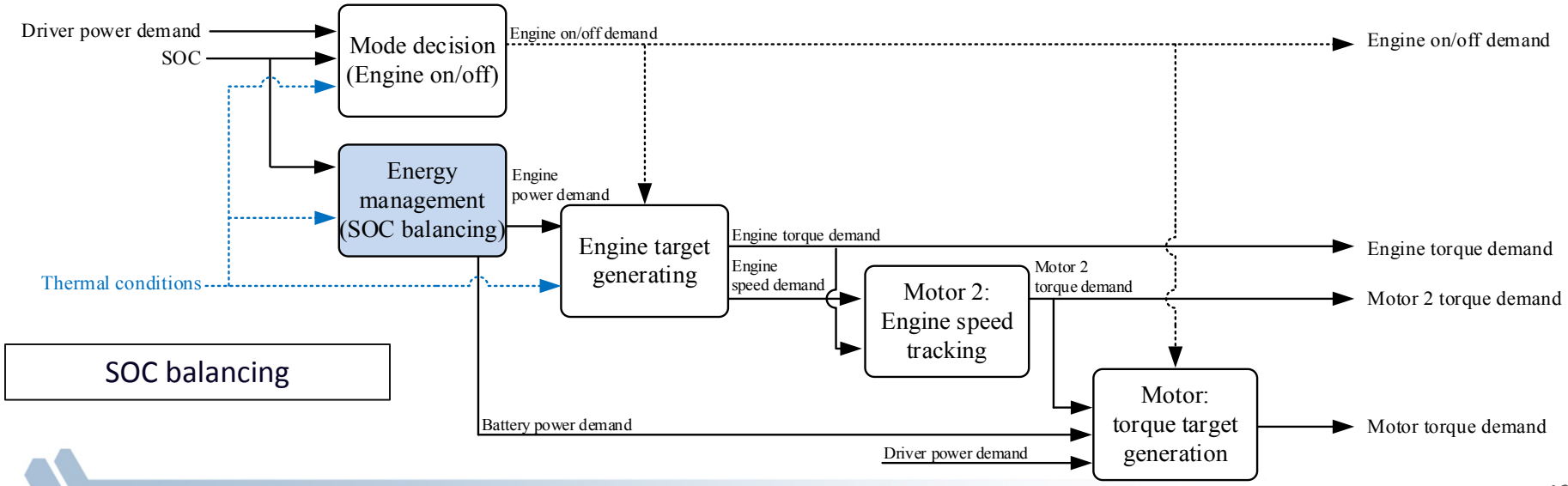
Technical Accomplishments

Analyze the control algorithm based on test data





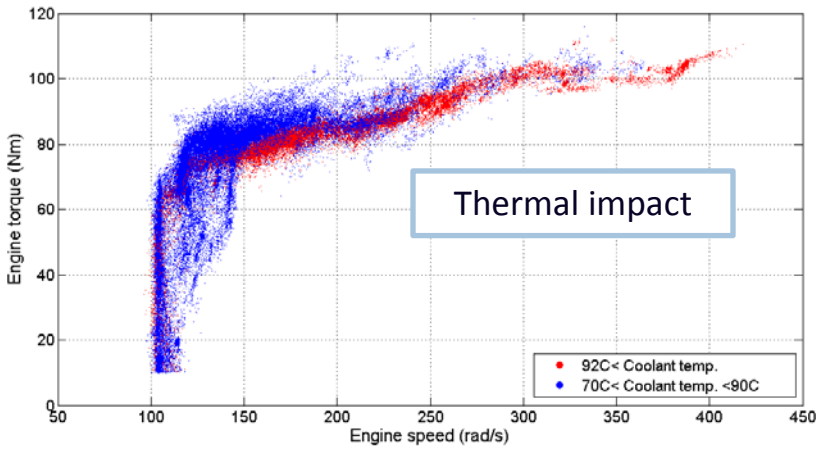
Thermal impact



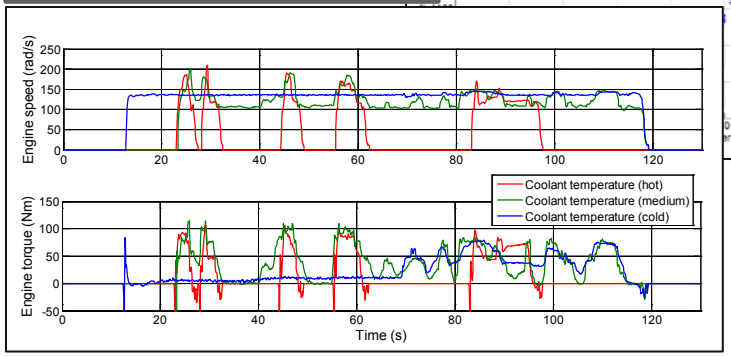
SOC balancing

Technical Accomplishments

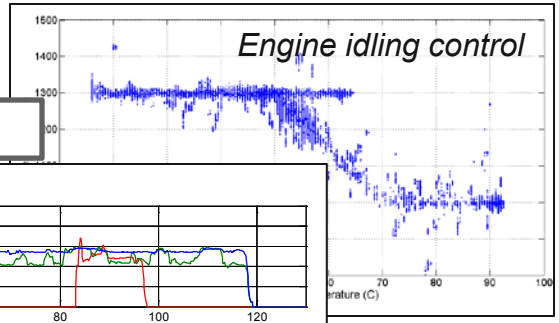
Analyze the control algorithm based on test data

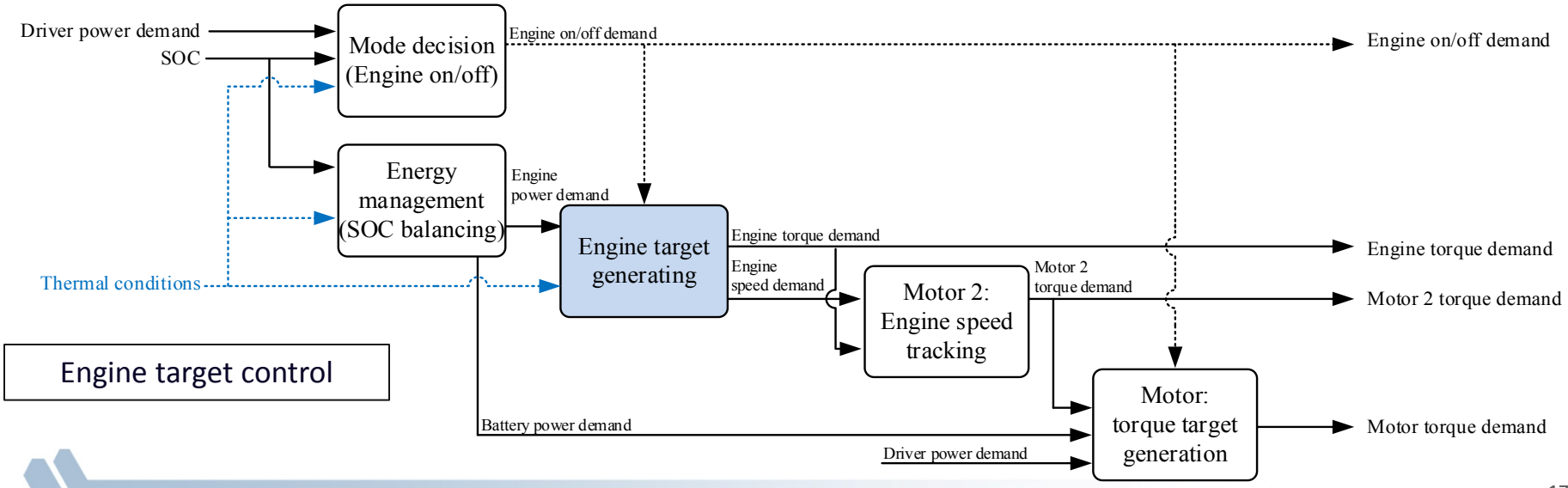


Cold condition behaviors



Engine idling control

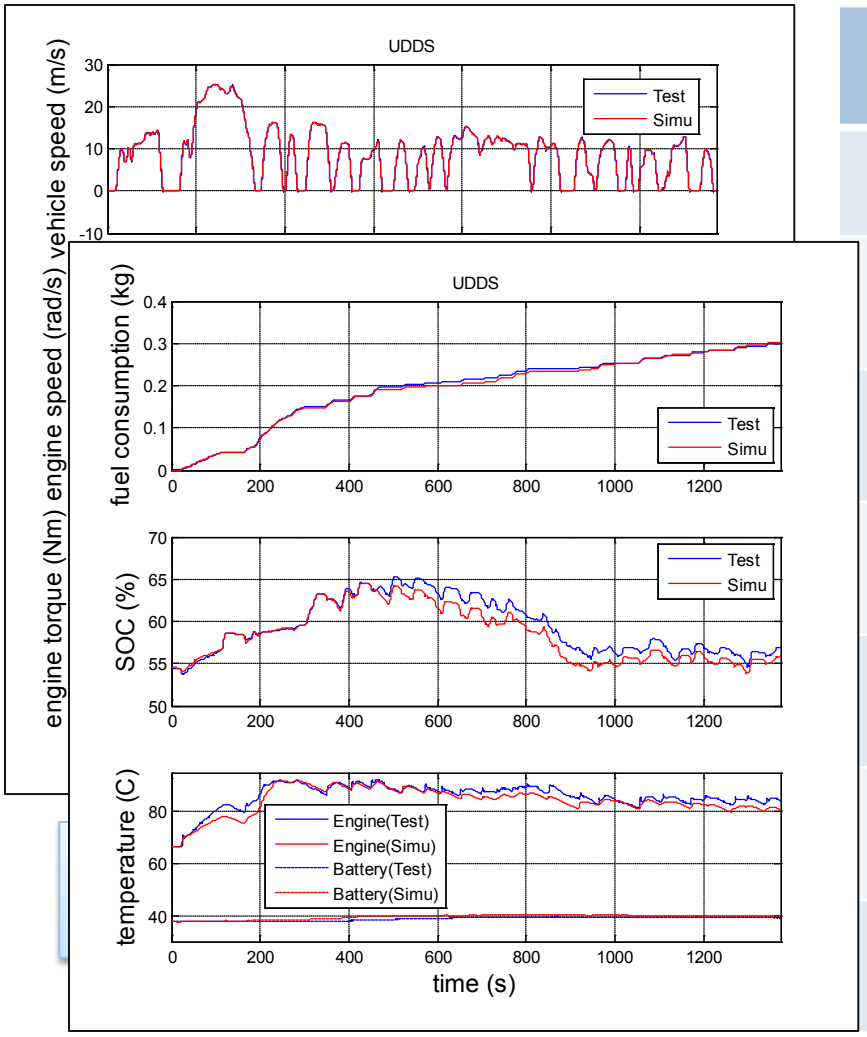




Engine target control

Technical Accomplishments

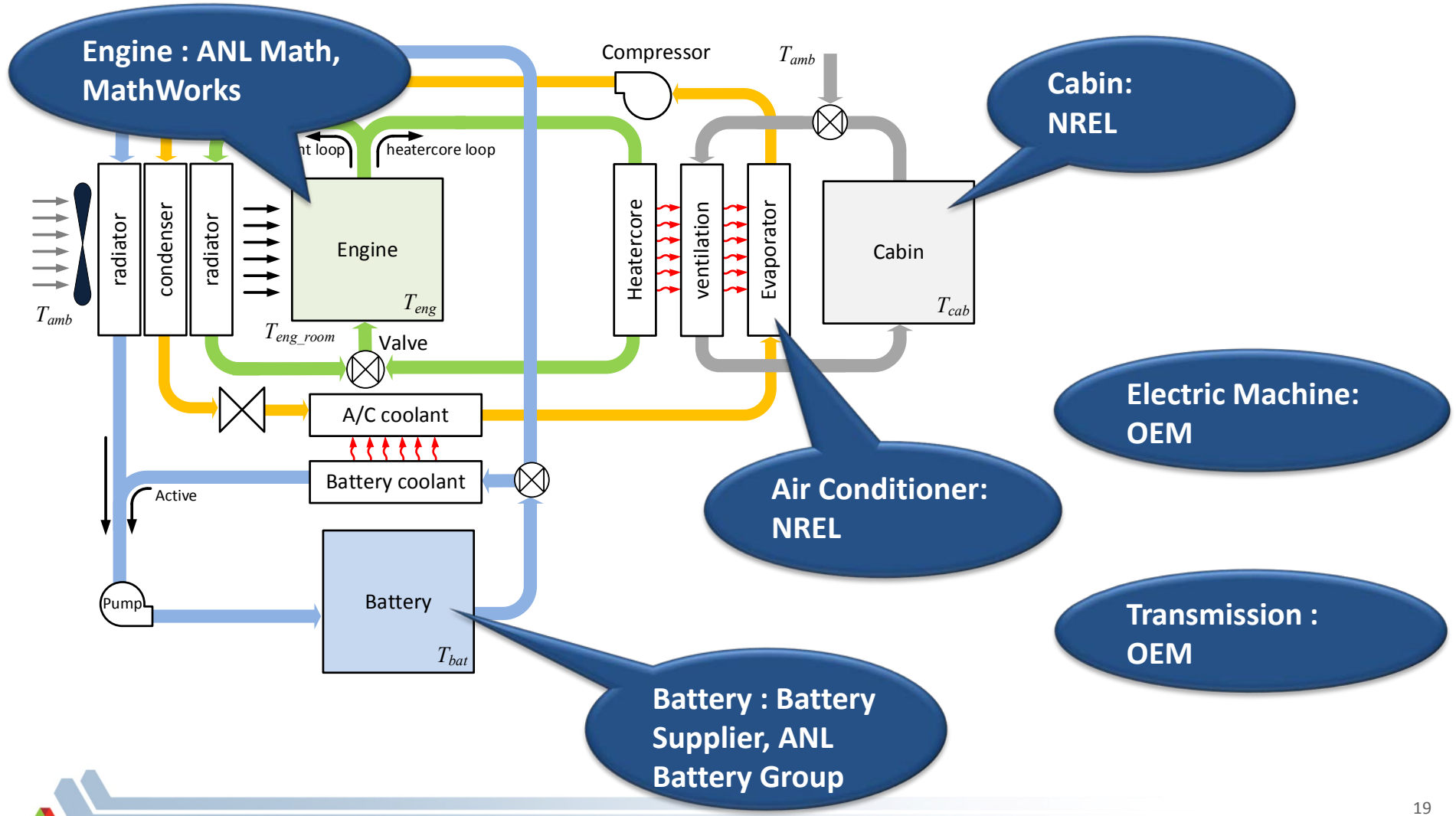
Toyota Prius HEV Thermal Validation Summary



	Fuel Mass Consumed (kg)			Final SOC		
	test	simu	Diff. (%)	test	simu	ΔSOC
UDDS (Normal)	0.300	0.303	1.2	56.9	55.8	-1.1
UDDS (Cold)	0.523	0.543	3.8	65.7	68.4	2.7
UDDS (Hot)	0.478	0.462	-3.3	50.8	48.2	-2.6
HWFET (Normal)	0.914	0.915	0.1	65.8	66.6	0.8
HWFET (Cold)	1.035	1.012	-2.2	65.8	66.2	0.4
HWFET (Hot)	1.089	1.104	1.4	64.6	64.3	-0.3

Collaboration with Other Institutions

Argonne has developed and integrated component thermal models working with a large number of experts



Proposed Future Activities

Continue to Develop and Validate Vehicle Thermal Model to Represent State of the Art Technologies

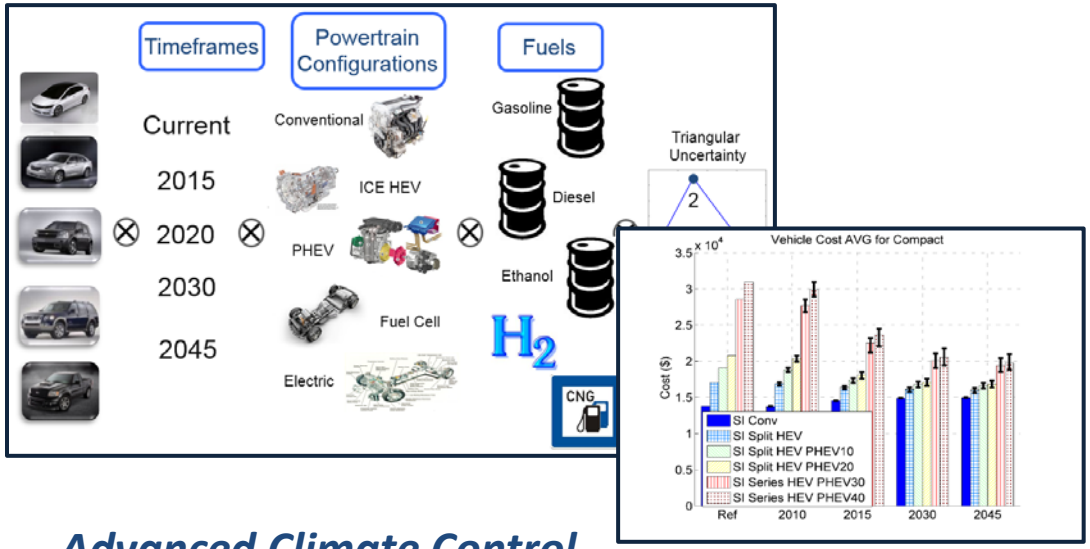
Work with expert groups (OEMs, Labs, etc.)

Enhance component models

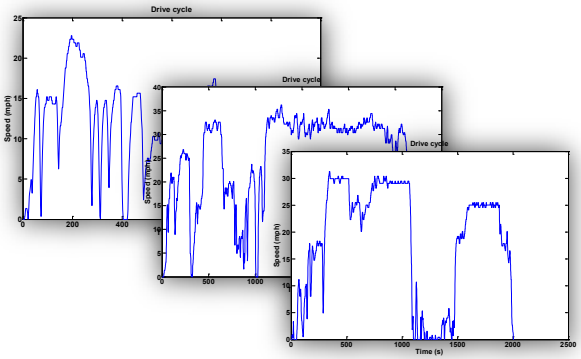
Proposed Future Activities

Quantify the Temperature Impact of Electrified Powertrains Under Different Driving Conditions and Temperature

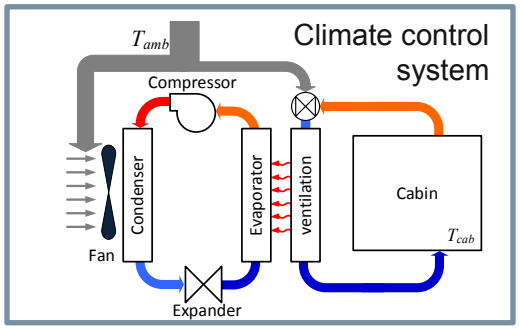
VTO R&D Benefits (Standard Cycles)

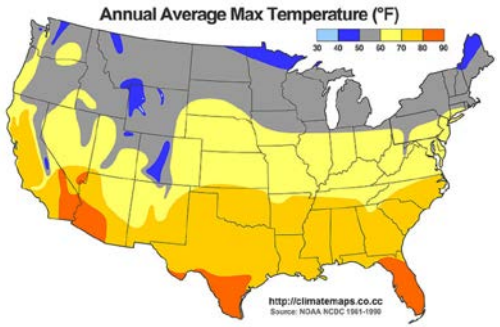


Real World Driving Cycles Under Different Temperatures



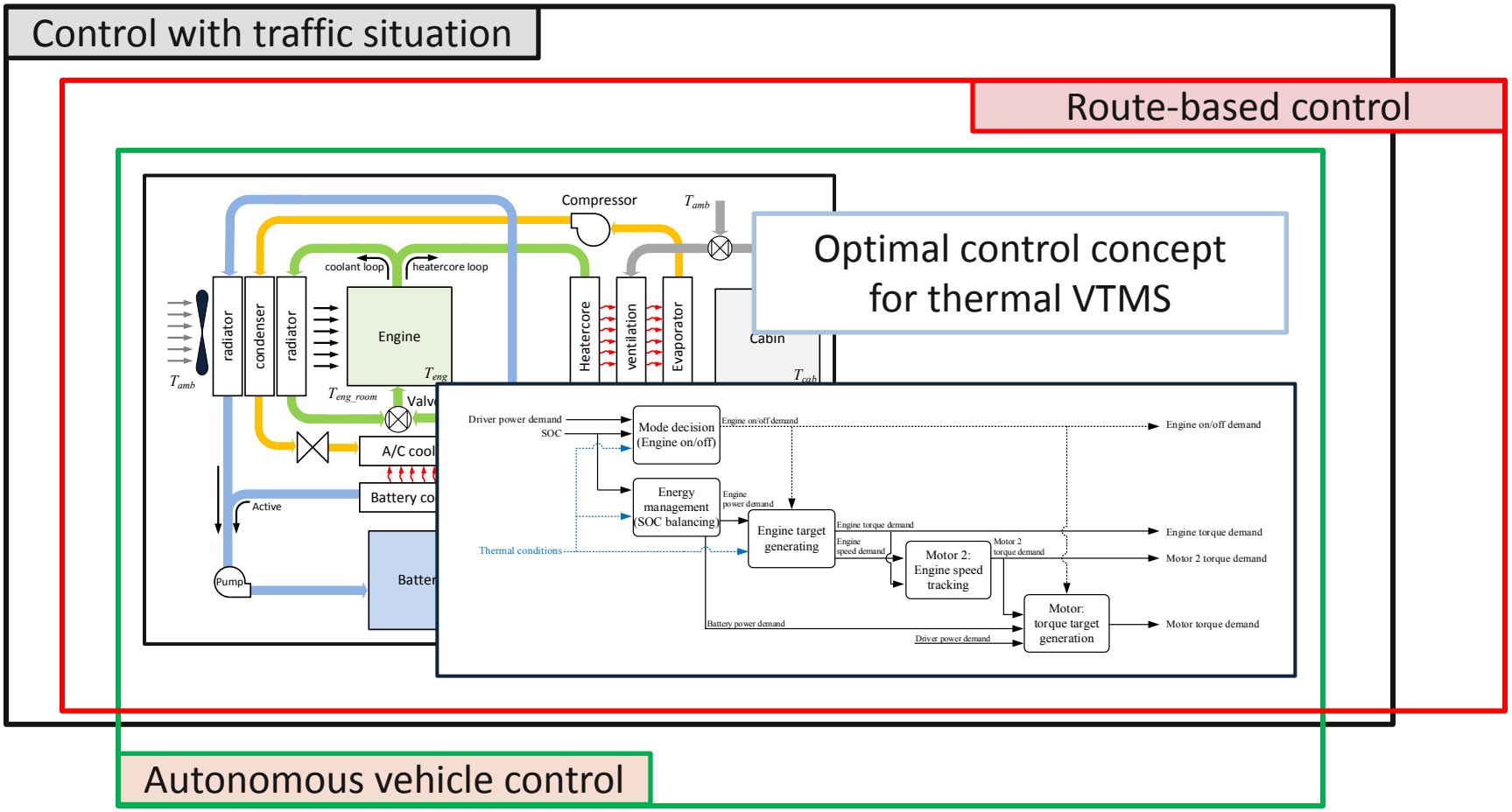
Advanced Climate Control (Collaboration with NREL)





Proposed Future Activities

Develop Advanced Controls to Mitigate the Impact of Temperature on Vehicle Energy Consumption



Summary

- Argonne keeps developing Vehicle Thermal Management System (VTMS) to have more realistic vehicle simulations
- VTMS is developed by following processes
  - Vehicles are tested under different thermal conditions
  - Import test data and analyze the control behaviors
  - Develop a controller model and thermal component models
  - Integrated the models into vehicle system and validate with test data
- Developed thermal models will be used in the future studies.
  - Keep improving thermal models for advanced vehicles
  - Large scale simulation to evaluate the impact of the thermal conditions
  - Optimal control for different thermal condition